

December 19, 1889.

Sir G. GABRIEL STOKES, Bart., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

- I. "Comparison of the Spectra of Nebulæ and Stars of Groups I and II with those of Comets and Auroræ." By J. NORMAN LOCKYER, F.R.S. Received November 9, 1889.

The discussion of cometary spectra which was communicated to the Royal Society in November, 1888,* contained, among other matters, conclusions which have a special bearing on the relations of their spectra to those of other bodies.

I have thought it therefore desirable to bring this new material together with the more complete lists of lines which are now available in the case of other groups of celestial bodies, chiefly owing to the observations made by my assistants and others and myself since my paper of 1887 was written, but also in consequence of a more complete search among previously recorded observations.

Such a comparison—a much more complete one than was possible in the first instance—would strengthen or weaken my hypothesis according as the increased area of observation increased or decreased the number of coincidences in the spectra of the various groups.

The more the coincidences are intensified the greater is the probability that comets, nebulæ, stars with bright lines, stars with mixed flutings, and the aurora have a common origin, independent of the chemical origins which have been assigned to the various lines by laboratory observations.

In the tables which follow, the individual observations are not given, but under each heading all the lines or flutings which have been recorded find place.

I. COMPARISON OF COMETS AND NEBULÆ.

We may conveniently begin with a comparison of comets and nebulæ. The Great Comet of 1882 and Comet Wells, when near perihelion, are excluded from the list of cometary lines and flutings, as their temperature was too high for fair comparison with most of the nebulæ and other low temperature phenomena.

* 'Roy. Soc. Proc.,' vol. 45, pp. 159—217.

In cases where any of these higher temperature lines correspond to lines in the comparison spectrum, however, they have been added to the list of cometary lines, in brackets, as sometimes the phenomena compared may attain a temperature slightly higher than that of comets at mean temperature.

For the nebulæ, all the lines recorded in the visible spectrum by Messrs. Huggins, Vogel, Copeland, Taylor, and Fowler are given. The list of lines has been considerably extended since my preliminary discussion of the spectra of nebulæ in November, 1887. D_3 and a line at 447 have been observed in the spectrum of the nebula in Orion by Copeland, and Mr. Taylor has also recorded D_3 and lines, or remnants of flutings, at 559 and 520. In the nebula in Andromeda, carbon flutings and the lead flutings at 546 have been observed by Mr. Fowler and confirmed by Mr. Taylor; since these observations were made, I find that Vogel* has observed a line at 518, probably carbon 517, in nebulæ numbered in Sir J. Herschel's General Catalogue 4234, 4373, and 4390.

Other nebula lines with which I was not previously acquainted are 479, 509, and 554. All these lines were observed by Vogel in the nebula G.C. 4378.†

With reference to the appearance of D_3 in nebulæ and bright-line stars, I wrote, in November, 1887‡:—"It is right that I should here point out that some observers of bright lines in these so-called stars have recorded a line in the yellow which they affirm to be in the position of D_3 ; while, on the other hand, in my experiments on meteorites, whether in the glow or in the air, I have seen no line occupying this position.

"I trust that some observer with greater optical means will think it worth his time to make a special inquiry on this point. The arguments against this line indicating the spectrum of the so-called helium are absolutely overwhelming. The helium line so far has only been seen in the very hottest part of the Sun which we can get at. It is there associated with b , and with lines of iron which require the largest coil and the largest jar to bring them out, whereas it is stated to have been observed in stars where the absence of iron lines and of b shows that the temperature is very low. Further, no trace of it was seen in Nova Cygni, and it has even been recorded in a spectrum in which C was absent, and once as the edge of a fluting.§

"It is even possible that the line in question merely occupies the

* 'Bothkamp, Beob.,' Heft 1, 1872, p. 57.

† 'Bothkamp, Beob.,' Heft 1, 1872, p. 57.

‡ 'Roy. Soc. Proc.,' vol. 43, p. 139.

§ " . . . The spectrum is very bright: two strong bands are seen in the red, then the D line, followed by a bright line (D_3) as the edge of a band" (Konkoly, "Neuer Stern bei χ Orionis," 'Astr. Nachr.,' No. 2712).

position of D_3 by reason of the displacement of D by motion of the 'stars' in the line of sight. On this point no information is at hand regarding any reference spectrum employed.

"If, however, it should eventually be established that the line is really D_3 , which probably represents a fine form of hydrogen, it can only be suggested that the degree of fineness which is brought about by temperature in the case of the Sun, is brought about in the spaces between meteorites by extreme tenuity."

The observations of Dr. Copeland* have now, I think, established the identity of the yellow line, in the nebula of Orion at all events, with D_3 . In a letter to Dr. Copeland, I suggested that the line at 447 was in all probability Lorenzoni's f of the chromosphere spectrum, seeing that it was associated both in the nebulae and chromosphere with hydrogen and D_3 . This he believes to be very probable. The line makes its appearance in the chromosphere spectrum about 75 times to 100 appearances of D_3 or the lines of hydrogen.

The association of the line at 447 with D_3 therefore strengthens the view that there is an action in space, away from condensations, whereby matter is reduced to its finest forms.

Comets.	Nebulae.	Probable origins.	λ of probable origins.
—	411	H	4101
431	—	CH	431
—	434	H	434
—	447	?	—
468—474	468—474	C (hot)	468—474
—	479	?	—
483	—	C (cool)	483
486	486·3	H	486
—	495	?	—
500	500	Mg	500
—	509	?	—
517	517	C (hot)	517
519	—	C (cool)	519
521	520	Mg	521
[527]	527	Fe	527
546	546	Pb	546
—	554	?	—
558	559	Mn	558
561	—	C (cool)	561
564	—	C (hot)	564
568	—	Pb, Na	568
—	5872	? (D_3)	—

The table shows that there are many striking similarities between the two spectra, and there is no doubt that many of the lines are

* 'Monthly Notices, R.A.S.,' vol. 48, p. 360.

identical. The flutings of hot carbon, for example, are common to both, as are also the flutings of magnesium, manganese, and lead. The hydrogen line 486 has only been seen in one comet, namely, Comet III, 1880, by Konkoly.*

Other flutings and lines again are special to comets and others to nebulæ. Thus, there are practically no indications of hydrogen in comets, although the hydrogen lines are amongst the brightest in nebulæ. Again, the lines 447, 479, 495, 509, 554, and 5872 are seen in nebulæ, but not in comets. On the other hand, the cool carbon flutings and the fluting at 568 are seen in comets, but not in nebulæ. Most of these apparent discrepancies are explained by a consideration of the differences in the conditions of comets and nebulæ. It must be remembered that in the case of comets there is an action which repels the vapours produced by collisions, and the vapours first affected will, of course, be those which are least dense. Hydrogen will thus be repelled from the comets, whilst the denser vapours of magnesium and carbon remain. There is then a good reason why hydrogen lines should *not* be seen in cometary spectra. As there can be no such repulsion in the sparse swarms which constitute nebulæ, hydrogen lines are seen in them.

Two other lines special to nebulæ are 5872 and 447, to which reference has already been made. The evidence tends to show that D_3 and f are finer vapours than hydrogen, and hence there is even greater reason for the absence of these lines from cometary spectra, even were the temperature higher, than for the absence of the lines of hydrogen.

The line at 527 is probably the iron line E; this was seen in the hotter comets, namely, Comet Wells and the Great Comet of 1882, so that there is no discordance with regard to the appearance of this line. The other lines special to nebulæ are 479, 495, 509, and 554; but as no origins for these have yet been determined, it is not possible to explain their absence from cometary spectra. It is not improbable that 554 is an error in measurement for the manganese fluting at 558, the latter having been recorded by Mr. Taylor in the nebula of Orion.

[On November 25, Mr. Fowler attempted to compare this line, as seen in the planetary nebula G.C. 4373, with the manganese fluting, but the line was so faint with the 10-inch that no reliable comparison could be made. The line is certainly not far from the manganese fluting.—December 8.]

The apparent absence of the cool carbon flutings from nebulæ is in all probability due to insufficient observations, as indicated by the discussion of comets. The lowest temperature (magnesium) and the hot carbon stages of comets are both represented in nebulæ, and the

intermediate cool carbon stage is therefore not likely to be entirely absent.

The absence of the hot carbon fluting at 564 from the spectra of nebulae may possibly be due to two causes. It is much fainter than either 517 or 468-474, and may have escaped notice on that account; or, as in the nebula in Andromeda, it may be masked in the same way as in comets.

It is suggested that the ordinary nebulae are not hot enough to give the line or fluting at 568, but it appears when the swarms become more condensed, that is, in bright-line stars. The absence of 568 is therefore probably due to the low temperature of nebulae.

II. COMPARISON OF COMETS AND AURORÆ.

If we exclude the exceptional cases of Comet Wells and the Great Comet of 1882, the number of lines and flutings recorded in comets is small, and therefore only the most general list of auroral lines must be taken for comparison. It would be unfair, for example, to take the long list of lines given by Gyllenskiöld. The lines stated are taken from the table which I gave in a note in January, 1888,* which has since been slightly rearranged before taking the means.

Comets.	Auroræ.	Probable origins.	λ of probable origins.
—	411	H	4101
[426]	426	?	?
431	431	CH	431
—	435	H	434
468—474	474—478	C (hot)	468—474
483	482	C (cool)	483
486	486	H	486
500	500	Mg	5006
517	517	C (hot)	517
519	519	C (cool)	519
521	522	Mg	521
—	531	?	—
—	535	Tl	535
—	539	Mn	540
546	545	Pb	546
558	558	Mn	558
561	—	C (cool)	561
564	—	C (hot)	564
568	—	Pb, Na	568
—	606	?	—
[615]	620	Fe	615
—	630	?	—

* 'Roy. Soc. Proc.,' vol. 43, p. 321.

Here, again, it will be seen, there are many striking coincidences. The hydrocarbon fluting at 431 and the hot and cool carbon flutings at 468—474, 483, 517, and 519 are common to both. The flutings of magnesium 500 and 521 and the flutings of lead and manganese at 546 and 558 are also common. The iron fluting at 615 is not seen in comets at ordinary temperatures, but since it was recorded in the Great Comet of 1882, it has been added, in brackets, to the list of cometary flutings. The line at 426, which was seen in Comet Wells, has also been added. It will be noted also that there are apparent discrepancies; some lines appearing only in comets and others only in auroræ. The explanation of the absence of hydrogen lines from comets which has already been given applies equally in this case. As there is no repulsion in the aurora similar to that exercised upon comets by the Sun, there is no reason for the absence of hydrogen. In the aurora the hydrogen lines may also be produced partly from aqueous vapour. The citron carbon flutings 561 and 564 have not been recorded in the aurora, although they are often seen in comets; their apparent absence from the aurora is probably because they fall in the brightest part of the continuous spectrum, and are consequently masked.

The lines special to auroræ are 531, 535, 539, 606, and 630.

III. COMPARISON BETWEEN COMETS AND BRIGHT-LINE STARS.

In the Bakerian Lecture for 1888 I gave a complete discussion of the spectra of bright-line stars, as far as the observations then went, and the conclusion arrived at was that they are nothing more than swarms of meteorites a little more condensed than those which we know as nebulæ. The main argument in favour of this conclusion was the presence of the bright fluting of carbon which extends from 468 to 474. This, standing out bright beyond their short continuous spectrum, gives rise to an apparent absorption-band in the blue. The varying measurements made by different observers may possibly have thrown a little doubt upon the conclusion that the bright band was due to carbon, but recent observations at Kensington have placed this beyond doubt. Direct comparisons of the spectrum of 2nd Cygnus with the flame of a spirit lamp were made by Mr. Fowler on September 22nd, and these showed an absolute coincidence of the bright band in the star with the blue band of carbon seen in the flame. The 10-inch equatorial and a spectroscope having one prism of 60° and two half-prisms were employed. On October 31st a similar comparison was made with 3rd Cygnus, and this also showed a perfect coincidence. It was found quite easy to get the narrow spectrum of the star superposed upon the broader spectrum of the flame, so that both could be observed simultaneously.

[On November 25, the spectrum of 1st Cygnus was observed by Mr. Fowler, and again he found a coincidence with the carbon fluting at 468—474. The observation was confirmed by Mr Baxandall.—December 9.]

Other evidence of carbon flutings was shown by slight rises in Vogel's light-curves near 517 and 564. These, however, could not be as well seen as the band in the blue, because they fall on the bright continuous spectrum from the meteorites. In the stars in Cygnus, Mr. Fowler detected brightenings near 517, and in 2nd and 3rd Cygnus, perfect coincidences were found with the fluting at 517 in the spirit-lamp flame. In this case both 517 and 468—474 were simultaneously seen to be coincident with flame-bands.

[In the observation of November 25, carbon 517 was also found in 1st Cygnus.—December 9.]

Measurements were made of the brightenings in the spectrum of γ -Cassiopeiæ by Mr. Fowler on September 18th, and these were also found to be coincident with the carbon flutings 517 and 468—474; the citron fluting at 564 was not seen. It may be remarked that C, F, and D₃ were seen very bright.

The conclusions drawn from my suggestions as to the presence of carbon, as well as hydrogen, in bright-line stars, are therefore strengthened.

In the following table, all the lines and flutings recorded in bright-line stars, with the exception of γ -Cassiopeiæ, are given. The lines recorded by Sherman in γ -Cassiopeiæ have not yet been confirmed.

Comets.	Bright-line stars.	Probable origins.	λ of probable origins.
—	4101	H	4101
431	—	CH	431
—	434	H	434
468—474	468—474	C (hot)	468—474
483	—	C (cool)	483
486	486	H	486
500	—	Mg	500
—	507	? Cd	508
517	517	C (hot)	517
519	—	C (cool)	519
521	—	Mg	521
[527]	527	Fe	527
—	540	Mn	540
546	—	Pb	546
558	558	Mn	558
561	—	C (cool)	561
564	564	C (hot)	564
568	568	Pb, Na	568
[579]	579	Fe	579
—	5872	? (D ₃)	—
[589 (D)]	589	Na (D)	5889, 5895
—	635	?	—

The coincidences here are between the flutings of hot carbon, manganese 558, and Pb, Na 568. D has only been seen bright in one of the stars (γ -Argus), which is probably one of the hottest; since D was seen bright in two of the hottest comets, I have inserted it in the list of cometary lines and flutings, and [527] and [579] are added for the same reason.

Although nine lines or flutings are common to comets and bright-line stars, six occur in comets which do not appear in bright-line stars, and five in bright-line stars which do not appear in comets.

The apparent absence of hydrogen from comets has already been referred to, as well as the absence of D_3 . The cool carbon flutings are not seen in the bright-line stars because the temperature is too high, and Mg 500 is absent for the same reason; Mg 521 is probably also absent because of the higher temperature. The lead fluting at 546 may be masked by continuous spectrum in the bright-line stars; at all events, it appears as an absorption-band when the swarms further condense. Besides the hydrogen and D_3 lines, the lines 507, 540, and 635 appear in bright-line stars, but not in comets.

IV. COMPARISON OF COMETS AND STARS OF THE MIXED FLUTING GROUP.

In the Bakerian Lecture I also gave evidence to show that stars of Group II (Vogel's Class III α) are of a cometary character, and a little more condensed than the bright-line stars. The grounds on which this conclusion was arrived at was the probable presence of bright carbon flutings, in addition to the metallic absorptions. Observations of α -Herculis and Mira Ceti by Mr. Fowler at Kensington and by myself at Westgate-on-Sea have fully confirmed this view. The rapid increase of brilliancy of the flutings of Mira at its maximum in 1888 left little doubt in my mind that they were due to carbon, and Mr. Fowler's comparisons showed perfect coincidences with the carbon flutings, with the dispersion of two prisms of 60°.

Some of the origins which I suggested for the dark bands have also been tested by direct comparisons. Dunér's bands 4 and 5 were found to be coincident with the manganese and lead flutings at 558 and 546 respectively, and band 3 was found to be coincident with the manganese fluting about 586.

[Mr. Maunder observed the spectrum of α -Orionis on December 16, 1887, and made comparisons with the spectra of carbon, sodium, and manganese, as given by a Bunsen flame. He states the results as

follows* :—“The carbon band at 5164 was coincident (within the limits of observation with this dispersion) with the bright space towards the blue of Band VI (Dunér's band 7), and the sodium lines were clearly represented by two dark lines near the middle of Band II (Dunér's band 3), but the two manganese bands observed, not only did not coincide with any great band of the spectrum, but were very far distant from any of them. There were, indeed, faint lines about the neighbourhood of either manganese band, but the entire spectrum is full of such lines, and no fluting, nor anything corresponding to one, could be detected near the place of these two bands. A third manganese band was very close to Band II (Dunér's band 3) of the stellar spectrum.” On the other hand, Vogel measured the position of the sharp edge of a fluting in α -Orionis as 559.1, and Dunér's measures for the same vary from 557.5 to 559.3, none of which can be described as “very far distant” from the manganese fluting near 558. Mr. Maunder's observation can only be explained by assuming that the band in question is variable. This might be produced by variations in the intensity of the carbon flutings; the manganese fluting falls on the carbon fluting near 564, and, according to their relative intensities, the manganese fluting will be visible or will be marked by the carbon. According to Gore, the star was at a minimum in December, 1887.

The fluting near 586 corresponds to Dunér's band 2, for which Dunér measures wave-lengths varying from 585.4 to 586.1. It apparently escaped Mr. Maunder's notice, at the time he made his observations, that no reference was made in my paper of November, 1887, to any band in the star spectra which fell near the third fluting of manganese near 535. The first two flutings, near 558 and 586, fell so near to two of the dark bands in the spectra of the stars of Group II that there was strong ground for believing them to be due to manganese. This has since been abundantly confirmed by Mr. Fowler's direct comparisons of the manganese flutings with the spectra of several stars of the group.—December 9.]

Under the heading of “Dunér's Bands” I give the mean wave-lengths measured by Dunér for the dark bands, and the limits of the bright spaces which are due to carbon.

The figures first given refer to the sharp edges of the flutings; the other figures indicate approximately where the flutings fade away.

This comparison shows that there is a very close relation between comets and Group II independent of the probable origins suggested. Bright carbon flutings, the manganese fluting at 558, the lead fluting at 546, the iron fluting at 615, and the magnesium fluting 521 are common.

* ‘Greenwich Observations,’ 1887, p. 22.

Comets.	Dunér's bands.		Probable origins.	λ of probable origin.
—	461—451	Bright space ..	C _B	460—451
—	461—473	(10) Dark space ..	—	—
468—474	472—476	Bright space ..	C (hot)	468—474
—	476—486	(9) Dark space ..	—	—
483	—	—	C (cool)	483
—	495—486	? Bright fluting.	?	—
500	495—502	(8) Dark fluting ..	Mg	500
517	516—502	Bright fluting.	C (hot)	517
519	—	—	C (cool)	519
521	516—522	(7) Dark fluting ..	Mg	521
—	524—527	(6) Dark fluting ..	Ba (2)	526
546	544—551	(5) Dark fluting ..	Pb	546
558	559—564	(4) Dark fluting ..	Mn (1)	558
561	—	—	C (cool)	561
564	—	—	C (hot)	564
—	585—594	(3) Dark fluting ..	Mn (2)	586
[615]	616—630	(2) Dark fluting ..	Fe	615
—	647—668	(1) Dark fluting ..	?	—

As I showed in the Bakerian Lecture, Mg 500, when not masked by the broad carbon fluting at 517, is probably indicated by the dark band, for which Dunér gives the value 502 to 495, so that this may also be regarded as common to Group II stars and comets.

The cool carbon flutings are seen in comets, but not in stars of Group II, the reason being that the temperature is too great. The hot carbon fluting at 564 is in all probability present in stars of Group II, but is always masked, in some cases by continuous spectrum, and in others by the absorption fluting of manganese, which is nearly coincident with it.

The line, or probably fluting, at 495 has not yet been recorded in comets, but its association with the fluting at 500 in Nova Cygni indicates that its apparent absence is entirely due to incomplete observations.

The second fluting of manganese, near 586, though one of the most prominent in stars of Group II, has not been observed in cometary spectra, probably because there is not sufficient continuous spectrum from the sparse meteoritic background of the comet to produce the absorption of more than the first fluting of manganese.

Dunér's band 1, 647 to 668, has not yet had an origin assigned to it.

V. GENERAL COMPARISONS.

In the preceding tables I have shown that the spectra of nebulae, auroræ, bright-line stars, and stars of Group II are closely related to the spectra of comets. In the table which follows all the spectra are

brought together and compared. It is not sufficient to show that each resembles comets in some respects, as each one might have some feature which was absent in the other. I, therefore, give the following table to show how far they resemble each other. In the last column the dark bands which are simply due to absence of radiation, and are not really absorption-bands, are omitted.

Nebulae.	Aurora.	Comets.	Bright-line stars.	Stars with mixed flutings.
4101	411	—	4101	—
—	426	[426]	—	—
—	431	—	—	449 (bright space)
434	435	—	434	—
447	—	—	—	—
—	—	—	—	461—451 bright
468—474	474—478	468—474	468—474	472—476 „
479	482	483	—	—
486	486	486	486	—
4958	—	—	—	4958—486 bright
500	500	500	—	502—4959 dark
509	—	—	507	—
517	517	517	517	516—502 bright
—	519	519	—	—
520	522	521	—	522—516 dark
—	—	—	—	524—527 dark
527	—	[527]	527	—
—	531	—	—	—
—	535	—	—	—
—	539	—	540	—
546	545	546	—	544—551 dark
554	—	—	—	—
559	558	558	558	559—564 dark
—	—	561	—	—
—	—	564	564	—
—	—	568	568	—
—	—	[579]	579	—
—	—	—	—	585—594 dark
5872 (D ₃)	—	—	5872	—
—	—	[589]	589	—
—	606	—	—	—
—	620	[615]	—	616—630 dark
—	630	—	635	—

It will be seen that there are three flutings which run through the five columns, namely, 468—474, 517, and 558; and four more, H 486, Mg 500, Mg 521, and Pb 546, occur in four out of the five columns. Out of the thirty-four lines or flutings given, there are nineteen which occur in less than three columns, but this number is greatly reduced when slight differences of temperature, masking effects, and the exceptional conditions of comets are taken into account.

It is now universally agreed that comets are swarms of meteorites,

and the tables which I have given show that nebulae, bright-line stars, stars with mixed flutings, and the aurora have spectra closely resembling those of comets, and are therefore probably also meteoritic phenomena.

II. "The Presence of Bright Carbon Flutings in the Spectra of Celestial Bodies." By J. NORMAN LOCKYER, F.R.S. Received November 23, 1889.

One of the chief conclusions arrived at in my former papers was that not only the nebulae but many of the so-called stars are really sparse groups of meteorites, the latter only differing from the former by the fact that they are more condensed. I also pointed out that if this conclusion were correct the spectra of both these classes of bodies should approximate to those of comets, in which carbon radiation is one of the chief features, while their meteoritic nature is generally accepted. Since those papers were written a further inquiry has been made, both by looking through the records of past observations, and by additional observations at Kensington and Westgate, with a view of gaining more information as to the presence or absence of bright carbon flutings in the spectra of nebulae and stars.

Certain results have already been obtained which I think sufficiently interesting to communicate to the Society. Before these observations were made, I suggested that some of Vogel's observations might be interpreted to signify bright carbon, but there was then a little doubt as to the existence of the bright flutings in the stellar spectra, as their presence was only suggested in some cases by slight rises in the light curves.

The following is a list of the bodies which contain either one or both of the carbon flutings near 517 and 468—474, the latter being a group of flutings, which, as I have before shown,* sometimes has its point of maximum brightness shifted from 474 to 468. The fluting near 564 has been omitted from the table, as it is generally masked, either by continuous spectrum or by the superposition of the fluting of manganese near 558. The wave-lengths given are as measured by the various observers stated.

The spectrum of the aurora is added for the sake of completeness.

It will be seen from the table that the record of the presence of carbon is unbroken from a planetary nebula through stars with bright lines to those resembling α Herculis, *i.e.*, entirely through Groups I and II of my classification.

* 'Roy. Soc. Proc.,' vol. 35, p. 167.